PERSPECTIVE

A River System to Watch: Documenting the Effects of Saltcedar (*Tamarix* spp.) Biocontrol in the Virgin River Valley

Heather L. Bateman, Tom L. Dudley, Dan W. Bean, Steven M. Ostoja, Kevin R. Hultine and Michael J. Kuehn

Throughout riparian areas of the southwestern United States, non-native saltcedar (also known as tamarisk; *Tamarix* spp.) can form dense, monotypic stands and is often reported to have detrimental effects on native plants and habitat quality (Everitt 1980; Shafroth et al. 2005). Natural resource managers of these riparian areas spend considerable time and resources controlling saltcedar using a variety of techniques, including chemical (Duncan and McDaniel 1998), mechanical, and burning methods (Shafroth et al. 2005). Approximately one billion dollars are spent each year on river restoration projects nationally (Bernhardt et al. 2005), and a majority of these projects focus on invasive species control in the Southwest (Follstad Shah et al. 2007).

A technique that has drawn much attention is the use of the saltcedar leaf beetle (*Diorhabda* spp.), a specialist herbivore, as biological control of saltcedar (Lewis et al. 2003). Research testing was conducted with beetles housed in secure enclosures in six states in 1998 and 1999 (Dudley et al. 2001), followed by open release at some of those sites starting in 2001 (DeLoach et al. 2004). By 2005, full-scale saltcedar biocontrol was implemented in 13 states, led by the USDA Animal and Plant Health Inspection Service (APHIS), the agency that oversees biological control programs, and with the participation and support of the U.S. Fish and Wildlife Service (USFWS). Despite the widespread application of *Diorhabda*, however, only limited research has quantified the consequences (benefits and costs) on biotic communities and ecosystem services. Alterations to riparian areas caused by various non-native species control activities have the potential to affect a variety of habitat types used by wildlife (Bateman et al. 2008a); processes like water availability, fluvial deposition, and erosion; and the establishment of other non-native species (Carruthers and D'Antonio 2005, Shafroth et al. 2005, DeLoach et al. 2006). Similarly, biocontrol is expected to modify riparian ecosystems, and it is imperative to document and evaluate both the environmental benefits and the potential costs of this tamarisk management method.

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Policy History of Saltcedar Biocontrol and Southwestern Willow Flycatcher

The Virgin River, with both extensive saltcedar stands and native vegetation, flows from Zion National Park in southwestern Utah through the northwest corner of Arizona and into Nevada, where it flows into Lake Mead (Figure 1). Downstream from Lake Mead is the lower Colorado River, another system heavily affected by saltcedar and where managers and biologists are interested in the impacts of biocontrol. In 2006, weed managers moved a biological control agent (*Diorhabda carinulata*) from central Utah south to the town of St. George (intrastate transport is not under the jurisdiction of APHIS) in an effort to control saltcedar infestations along the Virgin River.

Along this portion of the river and downstream from St. George, can be found the southwestern willow flycatcher (*Empidonax traillii extimus*), a passerine bird and federally endangered subspecies managed by the USFWS. The southwestern willow flycatcher builds its nest in saltcedar across a much of its range, but it also utilizes willow (*Salix* spp.), its historic breeding habitat. Flycatchers likely select nesting habitat based on the structure of the vegetation and not necessarily plant species composition (USFWS 2002). In a summary of what is known about willow flycatcher breeding and territorial behavior, Durst and others (2007) found nearly half (43%) of flycatcher nests were in native-dominated riparian vegetation such as willows; in other locations, the bird nested in a range of habitats from monotypic saltcedar (6%), saltcedar-dominated (22%), to mixed native-saltcedar (28%) habitats. Thus a potential conflict exists when an invasive species (saltcedar) provides habitat for an endangered subspecies (southwestern willow flycatcher). Beetle releases prior to the 2006 introduction to the Virgin River basin had all occurred outside of flycatcher territory, so this was a new situation.

The early observation of southwestern willow flycatcher nesting in saltcedar led to consultation between the USFWS

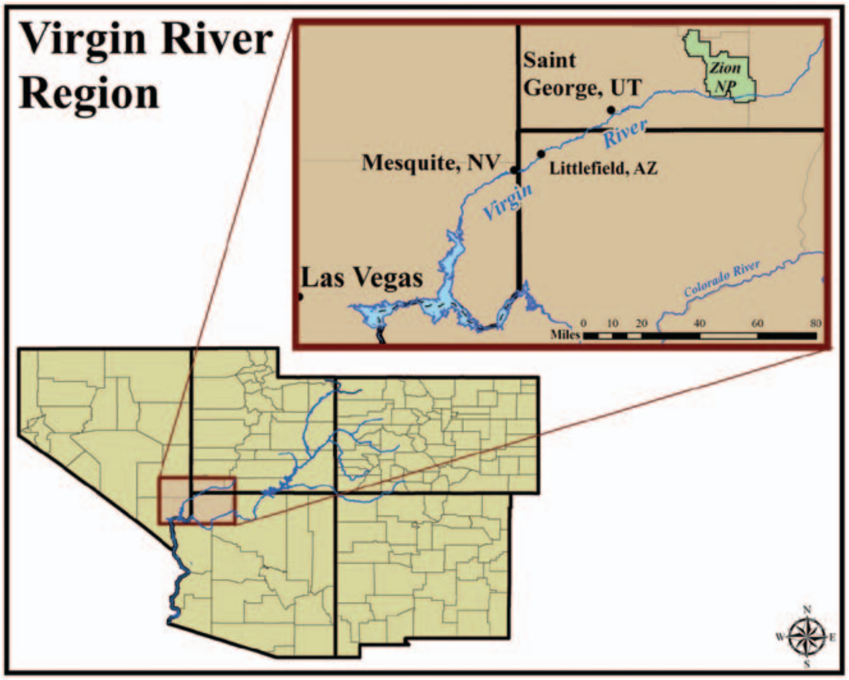

Figure 1. Location of the Virgin River Valley in the southwestern United States. Study sites for the Virgin River Biocontrol Project were established in 2009 along 50 km of the river from Littlefield, Arizona, south to Mormon Mesa in Nevada.

and APHIS (and its research collaborators) in 1999, with the outcome that *Diorhabda* research releases would be approved (by a Letter of Concurrence from USFWS) for saltcedar-infested locations only at sites at least 320 km away from locations where the bird was known to be using saltcedar for reproduction (not from southwestern willow flycatcher populations in general). The spatial buffer was also thought to provide a buffer in time. *Diorhabda* movement is an active area of current research, and beetles can move on the order of 40 km or more a year (D.W. Bean et al., unpub. data), although this hasn't been known until recently. Therefore, in 1999, it was assumed that the years it would take for *Diorhabda* to move into southwestern willow flycatcher territory would be enough time to achieve native plant recovery for flycatchers.

In 2009, the Center for Biological Diversity and Maricopa Audubon Society filed a lawsuit against APHIS and the USFWS on the grounds that the potential for *Diorhabda* movement into southwestern willow flycatcher territory had not been adequately evaluated in the original environmental assessment. The court dismissed the case since APHIS had reinitiated consultation with USFWS, but the lawsuit and threats of further litigation had a powerful negative impact on tamarisk biocontrol. This included a decision by APHIS to terminate all involvement in the saltcedar biological control implementation program and to revoke all permits, pending and existing, for interstate movement of *Diorhabda*, except to a small number of approved quarantine facilities. Most permits were revoked in the summer of 2009, and APHIS reiterated its policy of no involvement and no permits in a memo dated June 15, 2010, widely circulated among state and federal resource managers. The ban on interstate movement will be in effect until the completion of consultations between APHIS and USFWS. However, without recognizing political boundaries, the beetle has dispersed from its point of release in Utah across state lines and is defoliating saltcedar downstream into northern Arizona and Nevada. Nonetheless, it remains uncertain if interstate movement or open field releases will again be permitted by APHIS.

Controversy, Uncertainty, and Opportunity

The saltcedar biological control program has become a lightning rod for controversy, primarily because of concerns that beetles will defoliate saltcedar during the time of southwestern willow flycatcher nesting, altering habitat suitability for this federally listed subspecies. In a larger framework, the controversy revolves around disagreements among scientists, resource managers, and policy makers about whether *Diorhabda* releases will cause more short-term harm than long-term benefits to riparian ecosystem functioning in western North America. Uncertainty is fueled by the overall lack of quantifiable results on the impacts of saltcedar biocontrol agents on native species and ecosystem processes in a field setting (O'Meara et al. 2010).

At the same time, an unprecedented opportunity exists along the Virgin River, where a natural experiment permits scientists to inquire about the effects of *D. carinulata* in riparian systems by comparing the prebeetle environment to postbeetle defoliated conditions (Figure 2). Field effects are difficult to quantify because sufficient time is necessary for beetles to establish in a new region and begin defoliation. Therefore, results from the Virgin River are critical to inform the debate regarding the benefits and costs of *Diorhabda* release.

Figure 2. The Virgin River Valley approximately 5 km downstream of Littlefield AZ on June 1, 2010 (*left*), and 20 days later (*right*), showing non-native saltcedar (*Tamarix* sp.) defoliated from herbivory by the saltcedar leaf beetle (*Diorhabda carinulata*), a biological control agent. Photos by M.J. Kuehn

In 2009, a diverse team of scientists from academic institutions and government agencies established a suite of integrative and complementary research sites along 50 km of the Virgin River in Arizona and Nevada. The goal of the Virgin River project is to establish a long-term, interdisciplinary study program to document soil, plant, wildlife, and hydrological responses to the colonization and defoliation of saltcedar by *D. carinulata* and subsequent recovery of the riparian ecosystem via passive or active restoration. Another component includes measuring the evolution of life history traits, dispersal capabilities, and population dynamics of *D. carinulata* as it moves southward through the Virgin River Valley where environmental conditions are suboptimal. The species enters diapause, or suspension of development, based on day length, and the Virgin River Valley has shorter summer photoperiods compared to the more northern latitude of its native range (Bean et al. 2007). Therefore, *Diorhabda* could be limited by environmental cues to cease reproduction even when biotic conditions are favorable.

The Virgin River project will assess baseline conditions for several ecosystem processes prior to beetle establishment in monotypic saltcedar and in mixed native (cottonwood [*Populus* sp.], willow, and mesquite [*Prosopis* spp.])–saltcedar study plots. Two general impacts of *Diorhabda* establishment that are anticipated are alteration of the physical habitat structure as saltcedar is periodically defoliated and gradually dies back, and *Diorhabda* as a novel food resource available to insectivorous wildlife (Longland and Dudley 2008). In the short term, we predict some insectivorous vertebrates could experience an increase in abundance from *Diorhabda* food resources, whereas others may decline from habitat defoliation; in the longer term we predict possible water savings and lowered risk of fire in the Virgin River Valley (Table 1).

Results from research on the Virgin River can inform natural resource managers developing plans to prepare for *Diorhabda* establishment in riparian habitats. Without a comprehensive management plan, a window of opportunity will be missed to promote restoration of the Virgin River Valley to a native plant–dominated state. Saltcedar mortality rates from beetle herbivory can vary and depend on such factors as plant physiological stress, variation in water availability, and the seasonal timing of defoliation (DeLoach et al. 2006). Repeat defoliation within and between years typically leads to gradual dieback of branches and stems, which eventually resprout only from root crowns. For example, in northern Nevada (Humboldt River), saltcedar mortality did not occur until the third or fourth year of repeated defoliation (Dudley 2005), and in some heavily affected locations, mortality rates can reach 70% by the fifth or sixth year. If eradication of saltcedar is a goal, complementary management actions can be undertaken.

Prescribed fire is one method known to be effective to enhance mortality of already-stressed saltcedar and to reduce saltcedar biomass (Brooks et al. 2008). However, wildfire is also a threat in many areas dominated by saltcedar (Brooks et al. 2008). Therefore, a consequence of inaction is the risk of losing remaining native riparian habitat, such as cottonwoods, to fire (Busch 1995, Busch and Smith 1995). As the proportion of vegetation occupied by saltcedar increases, the risk of wildfire and mortality of associated native trees increases because both "green" and beetle-affected "brown" saltcedar foliage is more flammable than native riparian trees (G.M. Drus et al., unpub. data). Even with a reduction in saltcedar population sizes, planting native riparian species, such as cottonwoods and willows, is often desirable. The Virgin River project includes experimental trials to determine best methods for jump-starting recovery by planting native cottonwood, willow, and, in drier terrace environments, mesquite and acacia (*Acacia* spp.). Overall, site-specific management plans should include an understanding of

Table 1. Preliminary results and future research of the Virgin River research group to establish a long-term interdisciplinary program to document the dispersal and evolution of the saltcedar biological control agent (leaf beetle, *Diorhabda carinulata*) and its direct effects on soil, plants, wildlife, and hydrological responses. Data collection began in 2009 and the project is ongoing.

Research Topic	Pertinent Background	Progress & Preliminary Results	Research Questions & Predictions
Wildfire	Saltcedar burns when green, and continuity of biomass and litter promotes fire spread (G.M. Drus et al., unpub. data).	Defoliation moderately increases the flammability of saltcedar; fire enhances saltcedar mortality.	Fire risk will increase temporarily with saltcedar defoliation, then decline with gradual saltcedar biomass reduction; native plant mortality from wildfire will decrease as saltcedar dominance declines.
Water Conservation	Broad floodplains dominated by saltcedar have the potential for high evapotranspiration fluxes relative to river discharge (Shafroth et al. 2010).	Establishment of sap-flow and evapotranspiration monitoring equipment to document water loss to atmosphere before and after *Diorhabda* establishment	Alterations in functional leaf area by *Diorhabda* could result in reduction of evapotranspiration and greater mean annual river discharge; remote sensing data of vegetation will be used to calculate landscape level water savings.
Hydrology	Saltcedar may constrain flow channels (Birken and Cooper 2006) and promote overbank flooding.	Establishment of long-term channel profiles to assess channel form in relation to vegetation change	Gradual dieback of saltcedar will minimize vegetation loss and resultant erosion; reduced saltcedar density may allow larger flows within the channel.
Diorhabda	A univoltine (one generation per year) life history was thought to prevent *Diorhabda* establishment south of the 38th parallel (Lewis et al. 2003, Bean et al. 2007).	*D. carinulata* populations have dispersed more rapidly than predicted; *D. carinulata* requires photoperiod (day lengths) greater than 14 h 29 min to reproduce—approximately until August 5.	Life history traits will evolve to better match *D. carinulata* biology with resource availability.
Invertebrate Responses	It is possible that arthropod predators have low abundance in saltcedar monocultures, owing to lack of prey (Herrera et al. 2001).	Predators (Hemipterans, Coccinellidae, Salticidae, Formicidae, etc.) feed readily on *Diorhabda* larvae and/or adults.	Where predators are numerous (native vegetation common), they may inhibit *Diorhabda* establishment; predator guild will be enhanced by novel food source, creating a broader trophic base for riparian insectivores.
Vertebrate Responses			
Reptiles	Lizards respond positively to saltcedar and other non-native plant removal in New Mexico (Bateman et al. 2008b).	Species diversity in mixed native sites is marginally greater than that of monotypic saltcedar sites; lizards (*Aspidoscelis*, *Sceloporus*, *Uta*, and *Urosaurus* spp.) consume *Diorhabda*.	Defoliation may alter the thermal environment, benefiting ectothermic wildlife; insectivorous lizards may benefit by capitalizing on beetle food resources.
Birds	Insectivorous birds consume *Diorhabda* (Longland and Dudley 2008); avian diversity/abundance is lower in saltcedar than native habitats (Brand et al. 2008) but highest in native with intermediate levels of saltcedar (Van Riper et al. 2008); nesting success in native habitats is greater or not different than that in saltcedar (Brand et al. 2010).	Species diversity/abundance in monotypic saltcedar is lower than in native/saltcedar mixed habitats; a few species are *more* common in saltcedar (e.g., *Melozpiza melodia*, *Thryomanes bewickii*); nesting success is slightly higher in saltcedar (M.J. Kuehn unpub. data).	Insectivorous birds may benefit by capitalizing on beetle food resources; nesting success of some species may be negatively impacted by saltcedar defoliation. What are the long-term impacts of habitat loss (biocontrol) and replacement (restoration) on avian abundance and diversity?
Small Mammals	Shrews (*Notiosorex crawfordi*) do not respond to non-native plant removal in New Mexico (Chung-MacCoubrey et al. 2009); mice (*Peromyscus* spp.) consume *Diorhabda* (W.S. Longland unpub. data).	Species diversity in mixed native sites is markedly greater than that in monotypic saltcedar sites.	Insectivorous mammals may benefit by capitalizing on beetle food resources, especially during winter. How will defoliation affect small mammal abundance and diversity?

which conditions promote native vegetation or allow secondary weed invasion.

A System to Watch Long Term

River restoration requires quantifiable and long-term monitoring to document ecological improvement or unintended costs (Hultine et al. 2009; Merritt and Shafroth 2010). Managers must often balance the need to conserve native habitats and species with weed control (Dudley and DeLoach 2004). Therefore a comprehensive monitoring scheme is necessary when management must address potentially conflicting goals (Bateman et al. 2008a). Comprehensive plans should include monitoring responses from multiple taxa, establishing before vs. after experimental designs, and evaluating responses over large temporal and special scales.

The Virgin River is one of the first systems where scientists can document the effects of biocontrol on riparian system elements from wildlife to hydrology based on prebeetle conditions. This will be a system to watch in terms of increasing scientists' understanding of how biocontrol influences native invertebrate and vertebrate populations, habitat structure, plant water use, secondary weed establishment, and modifications to soils, hydrology, and fluvial processes. To better understand the consequences (both costs and benefits) of riparian restoration, projects addressing the ecological outcomes of such management activities should be prioritized and funded by both private and public sources (Follstad Shah et al. 2007). By contributing to our understanding of the ecological causes and consequences of alterations to riparian ecosystems from biocontrol, the Virgin River project will thereby help to establish the best scope and extent for restoration efforts.

Even with no further releases of *Diorhabda*, biocontrol populations can become large enough to sustain themselves, disperse on their own, and spread into new areas (Bean et al. 2007, Dalin et al., forthcoming). The immediate importance of the Virgin River studies will be to inform managers in the lower Colorado River drainage, where southwestern willow flycatchers and other riparian-obligate bird species breed and where saltcedar infestation is high and beetles are likely to colonize over time, either by natural selection for ability to establish further south, or by unregulated introduction of other *Diorhabda* forms capable of surviving at lower latitudes (Dalin et al., forthcoming). The large-scale implications of the Virgin River biocontrol project will be critical to informing the debate at the interface of ecology, policy, and restoration.

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Heather L. Bateman is an assistant professor in the Department of Applied Sciences and Mathematics at Arizona State University Polytechnic, 6073 S Backus Mall, Mesa, AZ 85212, heather.bateman@gmail.com.

Tom L. Dudley is a researcher at the Riparian Invasive Research Laboratory, Marine Science Institute, University of California Santa Barbara, CA 93106, tdudley@msi.ucsb.edu.

Dan W. Bean is Director of the Biological Pest Control Program, Conservation Services Division of the Colorado Department of Agriculture, 750 37.8 Rd., Palisade, CO 81526, dan.bean@ag.state.co.us.

Steven M. Ostoja is an ecologist for U.S. Geological Survey, Western Ecological Research Center, Yosemite Field Station, 5083 Foresta Road, El Portal, CA 95318, sostoja@usgs.gov.

Kevin R. Hultine is a research assistant professor at the University of Utah, Department of Biology, 255 South 1400 East Room 201, Salt Lake City, UT 84112, k.hultine@utah.edu.

Michael J. Kuehn is a research associate at the Riparian Invasive Research Laboratory, Marine Science Institute, University of California Santa Barbara, CA 93106, and also a research and collections assistant at the Western Foundation of Vertebrate Zoology, 439 Calle San Pablo, Camarillo, CA 93012, avian34@gmail.com.